Assessment of Market Power in Deregulated Electricity Market with Congestion

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***Abstract*—Restructuring of electrical market worldwide has brought the issue of market competition to the forefront. This new perspective has given rise to competition with the goal of price fall and technological innovation in the sector. In the last few years a great deal of attention is given to the possibility of a group of producers (agents) exercising market power by means of congestion effects. The possibility of two agents acting in a combined way on the Transmission System affecting the accessibility by the others to a specific Market is analyzed. This paper describes an algorithm used to detect measure and evaluate the impact of these kinds of strategic actions on market concentration. The results obtained from the study using 9 bus example network shows that this kind of actions can affect strongly market share and must be predicted by the Independent System Operator (ISO).**

***Index terms*—Electricity market, Market concentration, Market power, Power Transfer Distribution Factor (PTDF), System Interchange Capacity (SIC), congestion, power transmission.**

I. Introduction

The competitive electricity market structure is more related to oligopoly than perfect market competition. An oligopoly is a market structure where agent or group of agents has a partial influence on the overall market performance. The producers influence prices and payoffs. Nowadays the main electric energy markets have a motto of high competitive market in which every agent can sell energy to other agents.

The main goal of this kind of structure is to force the decrease of product price (electric energy) increasing innovation and integration of reliability and quality standards in electrical energy power systems [1].When one agent owns a share of market it has what is called market power and can start to act as a price-maker rather than a price-taker. Special attention must be given to the possibility of market power rise. The market power of an agent is a very important factor because it can change in a strong way the power market definition itself [2-3].

In general market power is referred to as the ability of market participants to maintain prices above competition level in a profitable way, for a significant period of time. When there is a price maker, there is some degree of market power .Market efficiency is obtained through competition, making market power undesirable, as it is a sign of low economic efficiency. Market power depends on the intrinsic characteristics of the electric power system. The transmission system is still an important part of the power system and directly depends from the ISO (Independent System Operator). Because transmission limits can be an important source of this market power, many models of strategic interaction on networks have been developed [4-5].

Congestion occurs whenever the transmission network is unable to accommodate all the desired transactions due to the violation of one or more constrains for the resulting state under both the base case and a set of specific contingencies. The open access transmission regime, results in the more intensive use of the transmission system witch, in turn, leads to more frequent congestion situations. The task of congestion management requires the ISO to identify and relieve such situations throughout the deployment of various physical or financial mechanisms.

For different power market structures, the approaches to managing congestion may vary. The electricity market behaves more like an oligopoly than an ideal market due to its special features such as, a limited number of producers, large investment size, and transmission constrains and natural or artificial congestion and transmission losses. Congestion, witch could isolate consumers from effective reach of some agents, and transmission losses witch discourage consumers from purchasing from distant suppliers.

When one agent owns a share of market it has what is called market power and can start to act as a price-maker rather than a price-taker. Special attention must be given to the possibility of market power rise. The market power of an agent is a very important factor because it can change in a strong way the power market definition itself [6]. Market power is harmful to competition and it is necessary to identify the potential for its abuse. It depends on the intrinsic characteristics of the electric power system. The transmission system is still an important part of the power system and directly depends from the ISO. Because transmission limits can be an important source of market power, many models of strategic interaction on networks have been developed [7].

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There are various definitions of market power. In general, market power is referred to as the ability of a market participant to profitably maintain prices above a competitive level for a significant period of time. An agent has market power if it can influence the market equilibrium point. Where there is a price maker, there is some degree of market power. Market power may range from a full market to a local market. Market efficiency is obtained through competition. Market power is undesirable, as it is a symptom of an uncompetitive industry and can lower economic efficiency. While the manifestation of market power abuse is usually associated with higher price above cost, it can also be lower quality of products or services compared to what would be found in a more competitive environment. Thus, it is not possible to measure market power only by calculating the percent price rise above cost. It is important to retain that market power it is not only limited to sellers. Buyers can also have market power. For example large customers have more ability to affect pricing than smaller ones.

In this paper, 9 bus system is considered to demonstrate the proposed method, which gives a quick and precise evaluation of market power and market concentration due to strategic coalition are proposed according to a specific image of the power market.

II. Market Power Evaluation

A Soursces of Market power

Market power can appear in two main forms: by market dominance and by transmission constrains. The market dominance is the market power of an agent that, in face of his dimension, can affect, in a strong way, the price. An example is the England and Wales pool where a highly concentrated market has allowed two dominant sellers – National Power and Power Gen.

Transmission constrains is the case closely analyzed in this paper, and reflects the existence of transmission congestion due to combined suppliers actions. A supplier can profit from increasing, rather than decreasing, production in specific points of the network, to create artificial line congestion, limiting the access of the competitors to a specific market. Congestion can, in fact, create conditions of market inefficiency in a short-term scenario. It is said that transmission systems introduce a degree of inefficiency into electricity markets [8].

B Market Power Analysis

Price increase above competitive levels is a manifestation of power market. Many factors should be taken in account when evaluating the competitiveness of an electricity market. It includes

- Market share
- Market concentration
- Elasticity of demand
- The amount and distribution of excess capacity
- Process of establishing prices
- Transmission system limitations.

The evaluation of the existence of market power own by one or more combined agents in Electric Power Market is done attending to the following issues:
- Identification of relevant products and services
-Identification of the geographical situation of the market
- Analysis of market share and market concentration
-Oligopoly equilibrium analysis.
In this paper a short-term scenario study is presented

C Market Concentrations

Market power can be evaluated based in the perfectly competitive equilibrium price. In general the first step to evaluate the competitiveness of market structure is to analyze market share of suppliers. After assigning market shares to each supplier it is easy to reflect these shares in an index of market concentration. Knowing the degree of concentration provides useful what other factors will have to be considered to enable a effective and easy way to find the existence of market power [9]. The most used process is to calculate the so-called HHI index (Herfindahl-Hirschman Index) [10].

The HHI is calculated for a precise market and traduces the accessibility distribution of the participants to the market. In a 'N' participant Network the HHI index is evaluated as in (1).

$$HHI = \sum_{i=1}^{N} (P_i)^2 \tag{1}$$

where P_i is the percentage of market owned by each participant.

For example, for four suppliers with shares of 10, 25, 45 and 20 percent the HHI would equal 3150 (100+625+2025+400) in contrast with HHI=2500 Corresponding to equal share. In the case of one generator having the totality of the Market Power the HHI calculation assumes its maximum value of 10000 (1002+0+0+0). The HHI approaches 0 when there are a large number of very small suppliers and equals 10000 when there is just one. HHI gives proportionally greater weight to the market share of the large suppliers and takes in account all suppliers in the market [11].

III. Power Transfer Distribution Factor (Ptdf)

The evaluation of the distribution of power market can be done using the power transfer distribution factors associated to a specific power transfer direction between two points– selling point and buying point. These factors express, in a linear approximation, the way a given transaction can affect the power flow in each of the lines on the network. The regular calculation of the PTDF is used by the ISO to validate transactions according to the physical limits of the lines [12-13].

Fig. 1 presents the example network used in this study where it is possible to calculate the PTDF for a given transaction. In this nine bus example network:
-Each node has a generator with limiting power generation of 500 MW and a load of 250 MW*;*

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– Each node is an agent that can buy and sell electric energy in the market;
- Each transmission line has a power limit of 200 MW and an impedance of j0.1p.u. (Active power losses in the network are neglected).

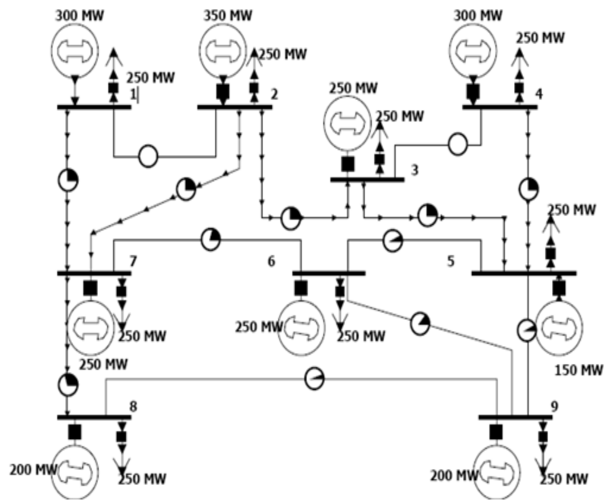

Fig.1 9 Bus Example Network

For a specific transaction, the PTDF calculation can be done. If node 1 is selling to node 9 100 MW the PTDF for each line can be calculated as in (2).

$$P_{ij\,1} = P_{ij} + PTDF(i,j,h,l) \cdot P_{hl} \tag{2}$$

where:

$P_{ij\,1}$ - Active power in line ij after transaction

P_{ij} - Active power in line ij before the transaction

h,l - Transaction direction (Selling node to Buying node)

P_{hl} - Power transaction in MW

IV. Transmission Line Congestion

If some agents control their individual generation in order to maximize their access to a given market, by limiting the access of the others, transmission line congestion is created. In fact, it is possible that by generation reconfiguration actions, some lines in the network become overloaded creating congestion zones modifying the market share.

Two agents can join efforts keeping their joint production unaltered and creating artificial congestion effects. Active power transmission limit is reached leading to a rise in market concentration. In the proposed study only two agents coalition is considered. For calculating the maximum congestion impact its necessary to obtain the sensibility factors that give the relation between the increases of power flow in each line with the increase on power generation in a specific node [14-15]. The calculation method proposed uses Power World Simulator (for power flow calculations and evaluation) combined with Mat Lab.

After obtaining the active power flow in each line P_{ij} we calculate the sensibility factors (*SENS*) as in (3).

$$SENS(h,l,i) = \Delta P(i) / \Delta P(h,l) \tag{3}$$

where:

$SENS(h,l,I)$ - Sensibility Factor for line h-l due to generator i

$\Delta P(h,l)$ - variation in active power flow in line h-l

$\Delta P(i)$ - generation variation in node i.

After calculating this factor for each line, it is possible to maximize the impact of generation reconfiguration in the transmission system. For this, it is necessary to solve an optimization problem represented in (4).

$$\Delta P_{hl} = max[SENS(h,l,i).\Delta P_i + SENS(h,l,i).\Delta P_j] \tag{4}$$

Sub.to

$$\sum_{K=i,j} \Delta P_{GK} = 0 \qquad \textit{Joint production}$$

$$P_{GKmin} \le \Delta P_{GK} \le P_{GKmax} \qquad \textit{Generation limits}$$

where:

ΔP_{hl} - variation in active power flow in line h-l

$SENS(h,l,i)$ - sensibility factor for line h-l due to generator i

$\Delta P(i)$ - generation variation in node i

ΔP_{GK} - variation in generation of node k

P_{GKmin} - minimum limit of generation on node k

After optimizing this problem for all lines is possible to evaluate the new power transmission limits for each line due to artificial congestion. It is possible to see that in the network of Fig. 1, for the proposed dispatch if agents 6 and 7 join efforts and alter their productions (keeping the total generation) to change in a strong way the active power flow in line 6-7 leading to an artificial congestion situation.

In this case the generator 6 produces 0 MW and generator 7 produces 500 MW (total generation still 500 MW). It can be seen that limit active power for line 6-7 is almost reached and HHI index is considerably raised. Fig. 2 shows the impact of such coalition. The upper and lower limit variation of active power (both ways) for each line after combined action leading to congestion effects can be calculated as in (5) taking into account the initial power flow in the line and the impact of the artificial congestion strategies.

$$\Delta P_{hl} \le (S_{max} - \Delta P_{congestion}) - S_{hl0} \tag{5}$$
$$\Delta P_{hl} \ge -(S_{max} + \Delta P_{congestion}) - S_{hl0}$$

where:

ΔP_{hl} - Variation of active power flow in line hl

S_{max} - Maximum apparent power flow limit

$\Delta P_{congestion}$ - Variation due to forced congestion

S_{hl0} - Power flow before congestion actions

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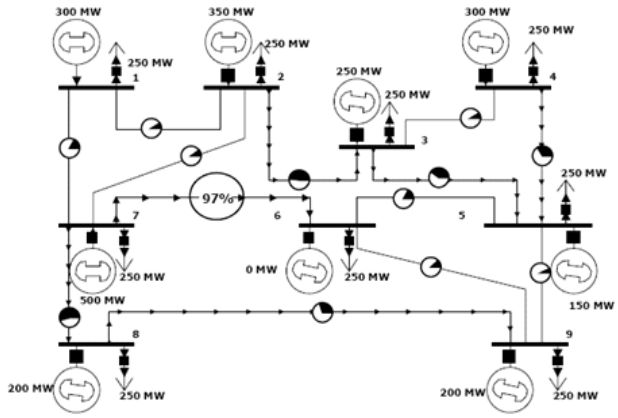

Fig.2. Impact in line 6-7 by combined action of 6 and 7

V. Proposed Market Evaluation

One way to evaluate the market share is to obtain the SIC (System Interchange Capacity) for each participant. This parameter traduces the maximum ability a specific agent has to sell power to some market. The SIC calculation gives a precise idea of how much power (maximum) an agent can sell to a precise market dealing with all the constrains in the network. This value depends on the network topology and conditions (generation, load, node voltage,). The congestion effects will be included in this proposed study in a pessimistic approach (maximum impact).Results obtained for the 9 bus example network, presented in Fig. 1.

In this example the market that was considered was the ability to sell to node 9. The SIC value is calculated for the initial network without congestion effects. In such situation all the agents have equal opportunity to sell power to agent 9. The SIC value is obtained by (6) searching the optimal solution (maximum) of function exportation to the buying node. In this case we will include the new line limits due to existence of coalition.

$$EXP = \max\left[\sum_{k=1\neq 9} \Delta P_{GK}\right] \qquad (6)$$

Sub.to

$$\sum_{k=1}^{N} \Delta P_{Gk} = 0$$

$$\sum_{k=1\neq 9}^{N} (PTDF(h,l,i,j) \leq (S_{\max} - S_{hl}) \text{ each line}$$

$$\sum_{k=1\neq 9}^{N} (PTDF(h,l,i,j) \geq (S_{\max} + S_{hl}) \text{ each line}$$

$$\Delta P_{GK} \geq 0 \text{ each line}$$

where:

S_{max} – *Transmission limit of line*

S_{max} – *power flow in line h-l*

P_{GK} – *Generation of node k*

EXP –Total Exportation.

The starting point for the used linear programming algorithm is the solution that corresponds to equal opportunity for each agent. The solution obtained from this kind of approach can be considered pessimistic because the coalition actions taken into account regarding the forced congestion actions are maximized. Considering the congestion effects the algorithm proposed can be described in the following steps:

- Consider all the possible coalitions of two agents and calculate the reconfiguration of generations in order to maximize forced congestion impact in all line transmission capacity;
- For each coalition calculate the new transmission capacity limit for each line;
- Make SIC calculations with the new line limits;
- Select the coalitions that affect the accessibility to the market for other agents;
- Calculate the HHI for each detected critical situation.

If this problem is solved without any kind of congestion effect the ability of each node to sell power to node 9 will be equal. Without congestion effects the SIC result for the 9 bus example network will correspond to 25 MW for each node .In face of artificial congestion situations the SIC will be different reflecting the existence of asymmetry in the market distribution and appearance of market power. The level of market power can be evaluated by the HHI for each critical coalition detected. Table I shows the HHI values for the detected critical coalitions in the 9 bus example network.

TABLE I
9 Bus HHI Values For Detected Critical Situations

Coalition	HHI
1<<>>6	1312
1<<>>8	1729
4<<>>8	2207
6<<>>7	1732
7<<>>8	2016

The HHI values for equal opportunities situation would be 1250. Fig 3 shows the results of SIC calculation. The SIC can give a quick and precise information of deformation in market share. HHI values validate the selected coalitions in fact; it is possible to see that market share can be in risk if joint actions of agents are introduced.

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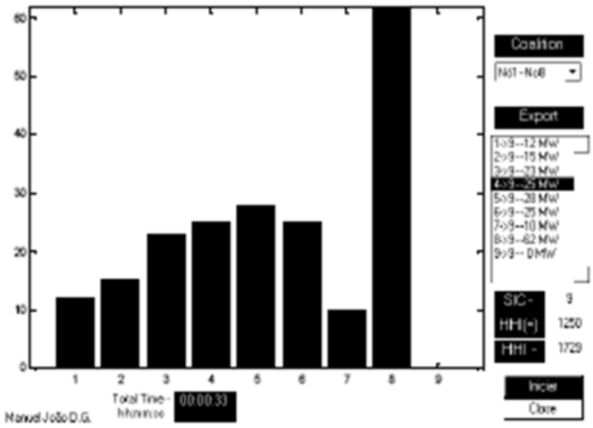

Fig.3. SIC results for 1-8 coalition

If the study is extended to the possibility of combined action of more than two agents the congestion effects in the transmission system would be more intense creating more deformation in SIC values and giving greater values for HHI giving rise to more market power. It is possible to conclude that in a high dimension network the possibility of creating artificial congestion effects would be more limited. But the number of coalitions leading to a SIC deformation would be higher. For a high dimension network we can talk about an influence zone of the two coalition agents that is limited by the physical dimension of the network.

Future improvements must be done in order to pre-select coalitions that do not represent any impact in SIC for all agents leading to less processing time. The obtained information can be very important for increase of the knowledge of electric energy market under open access and competitive strategies. The ISO roll in modern electric energy markets is fundamental for the reliability, quality and competitiveness of all the system.

VI. Conclusion

This paper deals with strategic coalition of two agents joining efforts to get some market power by means of forced transmission congestion. A possible method of detecting possible critical coalitions in open energy market is proposed. After detection and selection of possible critical coalitions a market power evaluation is performed. The study was done with an example network with positive results. It is possible to conclude that the algorithm proposed provide important information in respect to the possibility of strategic coalition's formation and how the establishment of them can affect the competitiveness and distribution of the energy market

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